5.0 Illustrative Sensor System Concepts

5.1 Improved Sensing Through Integrated Operations

In order to give a flavor of the changes, some radical and some evolutionary, that will occur as advanced technologies are introduced, we present in this section a set of system concepts to address difficult sensing challenges like those raised in Section 4. Improvements in sensor system capability will come about in two fundamental ways. First, almost any type of sensor offers opportunities for improvement in performance, reliability, and cost through the use of better materials and designs. The second and far more powerful approach involves the integration of multiple sensors in an information fabric that achieves high levels of dimensionality and target coverage. The basic issues of a “system of systems” architecture were discussed in Section 2. This overall theme of sensor internetting and cooperative operation underlies much of our thinking about the future of sensor systems.

For any given sensor task, there are innumerable potential system solutions. Our purpose here is not so much to prescribe in detail the systems and networks the Air Force should pursue as to stimulate thinking about innovative ways to apply technology to solve operational problems and to suggest ways in that future sensor systems will differ from today’s inventory. The overall goal in constructing these concepts is to leverage technology opportunities in ways that are feasible and affordable while yielding major improvements in capability. We seek new ideas that will capture the power of advanced technology while at the same time ensuring that concepts are consistent with technologies that will be available in the time frame of *New World Vistas*. In each of the following subsections, an illustrative concept is described in terms of the elements and functions of the conceptual system and a discussion of the enabling technologies needed to implement it.

5.2 Summaries of Concepts

The following paragraphs describe seven widely varying concepts. They have in common the ideas of applying multiple sensing mechanisms (high degrees of dimensionality), powerful algorithms and processors, and extensive integration of systems and functions.

5.2.1 Concept 1—Target Reporter

5.2.1.1 Overview

This concept speaks to the use of advanced sensors and platforms to achieve timely, comprehensive situational awareness of the battlespace. A UAV maintains a 72 hour on-station orbit, providing continuous surveillance of key LOC (roads, canals, rivers, ports, rail lines) segments (passes, intersections, bridges, choke points) over a large battle area (200 by 400 nm), using automated ESM, MTI and UGS coverage of those key points. Spot SAR sensors are used to map segments for which analysis indicates targets. An ATR subsystem identifies traffic to verify activity and validate analysis, and report targets. The UAV broadcasts traffic and target reports for mission planning and execution functions. Figure 5-1 depicts the concept.

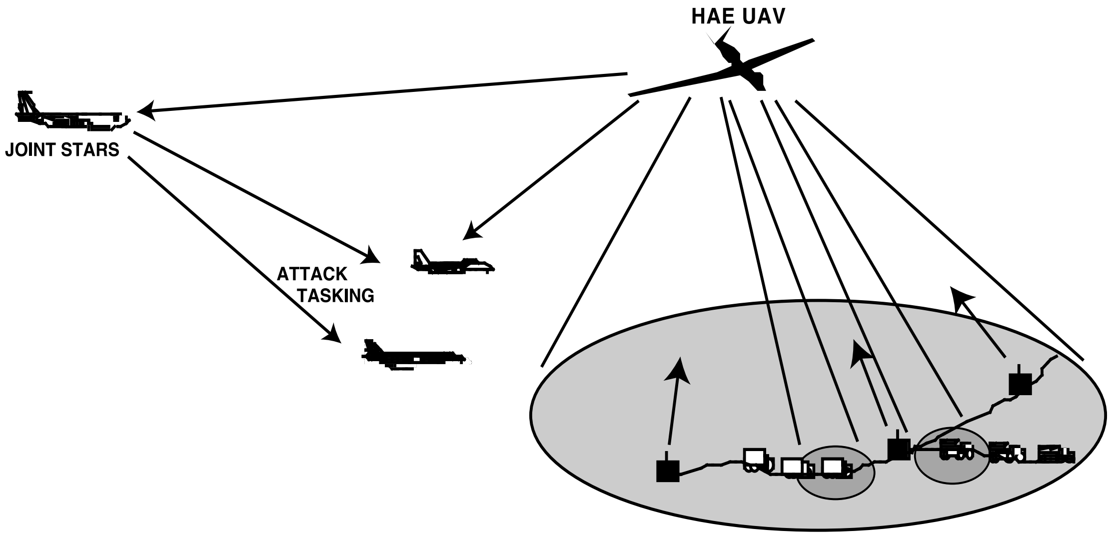

Figure 5-1. The Target Reporter Concept Supports Dynamic Battle Command and Control

5.2.1.2 Sensor Concept

The Target Reporter provides direct support to military operations by providing high accuracy target identification, location, and context to the battle control elements and to the shooters at very low communications data rates and with few false alarms. Targets include fixed target activity, mobile targets, and targets obscured by foliage or other types of camouflage, concealment and deception (CC&D). It supports the Air Force missions of Suppression of Enemy Air Defenses (SEAD), Offensive Counterair, Interdiction, Close Air Support (CAS), Surveillance and Reconnaissance, and Special Operations, including MOOTW.

The Target Reporter sensor system suite includes advanced sensors to accomplish the elements of its mission:

- **(UAV)**. The UAV for this target reporter concept is a high altitude endurance (HAE) platform with a 72 hour on-station time at 65,000 feet or higher altitude, a gross weight of 30,000 lbs and a payload capacity of 4000 lbs. It is based on advanced propulsion technology and lightweight structures.
- **ESM**. The ESM system is used to detect, analyze, and locate electromagnetic emissions associated with military operations. This could include radar emissions associated with air defense systems, communications emissions associated with command and control, and general emanations associated with air and ground weapons. The ESM provides moderate accuracy of location, sufficient to cue the imaging sensors to provide more accurate identification and location data. ESM also provides essential elements of target classification and identification.

- **MTI Radar**. The large aperture MTI radar, including ground moving target indicator (GMTI) modes for vehicle targets, provides a situation picture of a large battlespace (200 nm range) to present the commander with the "big picture." Moreover, the MTI radar would be cued to frequently or continuously observe key segments of lines of communication (road intersections, runways, heliports, marshaling yards, rail lines, etc.) for activity to compile time histories from which activity patterns can be analyzed and future actions predicted. In addition, the analysis of the MTI returns offers moderate accuracy target identification and moderate accuracy location of potential targets in order to cue the imaging sensors.
- **UGS**. An internetted wide area network of air-delivered and air-monitored unattended ground sensors (see Section 5.2.2) would be multiphenomenological including acoustic, seismic, and magnetic based transducers, and the associated sensor processing. The UGS system could also be covertly seeded at critical movement points or at facilities from which personnel or vehicles could depart. Sensors would classify targets and report to the UAV via a low-probability-of-intercept (LPI) communications link.
- **SAR**. The synthetic aperture radar will provide broad area coverage (5 km by 5 km) at moderate resolution and will adaptively provide focused imaging at high resolution (down to 0.3 m) when cued by analysis of wide area images or by other sensors such as ESM and MTI. High resolution imagery will support target location with an accuracy of 10 m as well as a major source of data for target identification. For general imaging, X-band is probably optimal, while the desired capability to penetrate foliage suggests selection of a wide bandwidth VHF frequency. Technology advances allow progress toward broadband and eventually multiband radars.
- **ATR**. The automatic target recognition provides analysis of MTI, UGS, and SAR returns to provide accurate determination of the target class and identity. It makes use of existing information on the environment (terrain, weather, urban activity, etc.) provided to the system in advance, and uses model-based vision techniques for accurate targeting decisions. Much of this processing is performed onboard the Target Reporter to speed up the overall engagement loop from target detection to strike and to reduce the transmission of low-content raw data to higher fusion centers.
- **ASC**. The automatic sensor cueing capability provides analysis of MTI, ESM and UGS returns to provide accurate cueing of the imaging SAR to a suspected target or situation. It exploits analysis of single and multiple sensor returns.

5.2.1.3 Enabling Technologies

The Target Reporter, with the individual sensor concepts discussed above, requires the development of many sensor and supporting technologies. Some are:

- Lightweight, low cost radar apertures with broad bandwidth (600 MHz) that are tunable over at least an octave, high DC-RF conversion efficiency, and excellent beam control (e.g., multiple null steering to defeat jamming).

- ATR algorithms and compact, high performance processors that optimally combine the full range of available sensor data streams for high quality target detection in clutter and real time classification or identification.
- ASC algorithms for MTI radar, ESM, and UGS returns.
- Micro-miniature, internetted, unattended ground sensors (see Section 5.2.2).
- Robust, LPI, anti-jam data links for bitways among Target Reporter platforms, other C^3I nodes, and attackers.

5.2.2 Concept 2—Integrated Arrays of Distributed Unattended Ground Sensors

5.2.2.1 Overview

Many difficult information collection tasks can be attacked by “saturating” a facility, an area, or an entire theater with small sensing devices equipped with a variety of detectors. These units are often most effectively seeded by aerial delivery systems and monitored by aerial relay platforms such as UAVs to keep data link ranges short. These devices will use low power microelectronics and simple, but robust, data links to hold down size, power consumption, and cost. Detectors for acoustic, seismic, chemical/biological species, ESM/SIGINT, magnetic, and possibly other variables can be combined in a UGS package for specific applications. UGS can be used to monitor facilities such as NBC weapons sites and command centers, to report vehicle traffic and in some cases to classify individual vehicles, and to do many other subtle and diverse sensing tasks. They are inherently covert, and a UGS array is robust in that discovery and removal of individual units by the enemy represents only a fractional loss of capability. Figure 5-2 illustrates a typical scenario in which a variety of UGS monitors a hardened facility and the traffic on a road.

5.2.2.2 Sensor Concept

Microsensors can be integrated with a variety of packaging and mobility schemes. The concept envisions extensive use of unattended ground sensors, including both fixed packages and small flying or crawling mechanisms able to penetrate hostile facilities. For maximum effectiveness and affordability, a set of modular detection elements for various variables (sound, seismic vibrations, chemical species, RF signals, etc.) would be mixed and matched in a given package for a specific need. See Section 5.2.3 for a fuller description of the use of such sensors to measure buried structures. Among the many other situations in which this concept has great potential are detection of trace effluents associated with NBC facilities and ESM/SIGINT interception based on placing receivers very close to communication systems and lines.

As important as the sensors themselves are the methods for collecting and exploiting the data they produce. Individual sensors will report activity in a manner much like cellular telephones going from one repeater cell to the next. Rough tracks and target counts can be derived along with the characteristics that help identify targets. This data will be fused and assessed with other sensor outputs, intelligence, and other information and presented to commanders, controllers, and shooters in support of situational awareness, planning, and engagement control.

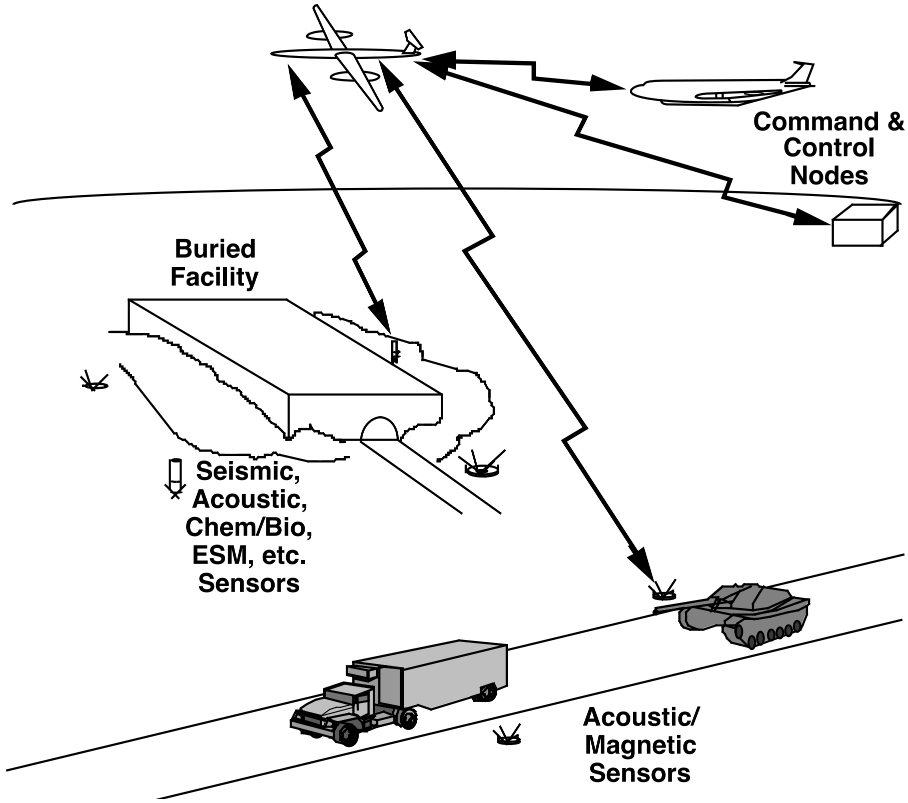

Figure 5-2. Typical Uses of Microsensors With Multiple Detector Types Include Covert Surveillance of Facilities and Monitoring Traffic

5.2.2.3 Enabling Technologies

Although many components of microsensors like those described in this concept are available (e.g., miniaturized RF transceivers, acoustic sensors, etc.), a number of technology improvements affecting both packages and detectors are key to successful implementation. These include:

- MEMS as a basic method of designing and fabricating many kinds of microsensor structures and actuators.
- Very low power, LPI data links with matching relay packages for UAVs and other platforms.
- Very high energy density batteries.
- Sensitive, high resolution sensing elements, especially for variables with no commercial equivalent such as chemical/biological agents.
- Effective algorithms for fusing microsensor data with other sources and for flexible, easily interpreted information display.

5.2.3 Concept 3—Underground Target Surveillance

5.2.3.1 Overview

In this concept, a UAV maintains surveillance of known underground facilities containing such activities as NBC production and storage, high echelon command and control, weapon storage, and general equipment storage. Structures will normally include tunnels, buildings, and caves, but might also include the rubble of a destroyed building. Capabilities associated with counter-drug and counter-terrorist below-ground surveillance are also highly important.

The system concept, shown in Figure 5-3, while primarily employing a UAV, also includes off-board sensors. On the UAV, the sensor system would consist of a multispectral EO sensor with active and passive modes (e.g., differential absorption laser radar) to detect and identify effluents, a spot synthetic aperture radar, and a seismic tomography stimulator. Off board (and linked to the UAV) would be an air-seeded UGS array associated with the seismic tomography concept and, when appropriate, other UGS types such as acoustic traffic and activity monitors, ESM collectors, and ground-level chemical/biological agent detectors.

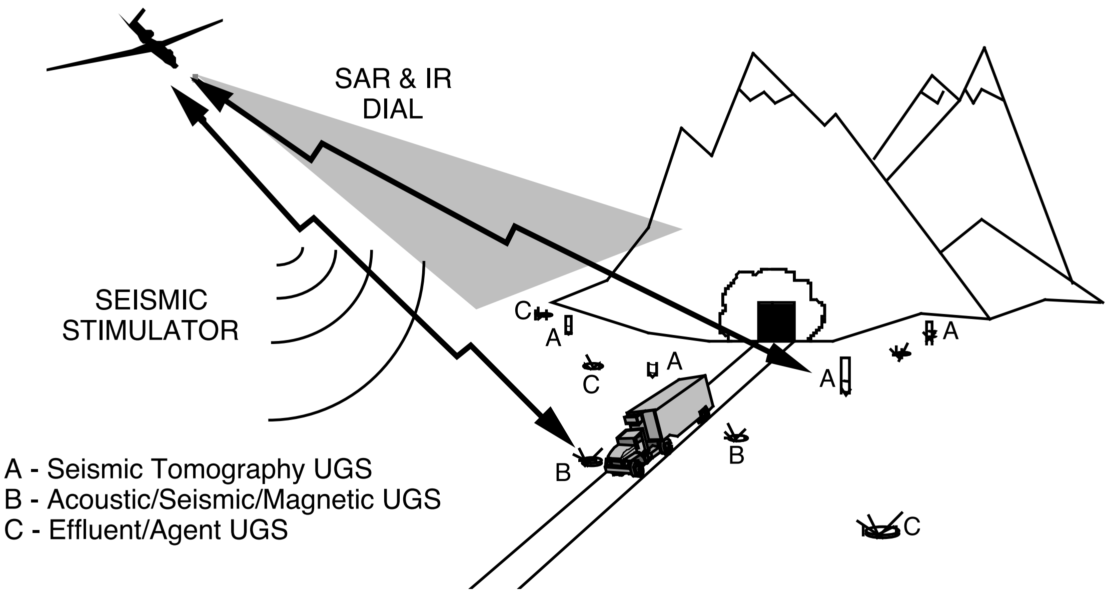

Figure 5-3. Underground Target Surveillance Concept

5.2.3.2 Sensor Concept

This concept brings a variety of sensor and platform technologies together to deal with the difficult and growing problem of buried and hardened facilities. The surveillance of underground facilities is key to monitoring and targeting the activities of enemy leadership, detecting and classifying weapons manufacture and storage (especially NBC materials and weapons), and locating and classifying command and control sites. It is also essential to tracking transfers of personnel (including captives), weapons, and other equipment and to dealing with many counter-terrorism, drug interdiction, and similar tasks.

The concept includes the following sensors:

- **DIAL**. The DIAL sensor has the capability to be cued to underground facility locations and to analyze effluent gases by differential absorption of the return associated with the transmission of two or more laser lines (wavelengths). The active sensor can be supplemented with multi- or hyperspectral passive sensors to extend the range of chemicals detected.

- **RF/Seismic Tomography System**. The radio frequency/seismic tomography system uses a bistatic approach in which either or both electromagnetic and seismic waves are transmitted from the UAV into the ground to be received by implanted UGS in a tomographic scheme to construct a three-dimensional map of the electromagnetic and seismic properties of the volume observed. The stimulator could also be a natural noise (like thunder), an independent generator (like a bomb or gunfire), or a "thumper" implanted as part of the UGS array. Seismic waves respond to mechanical (elastic) properties of the volume, while electromagnetic waves respond to the electrical properties. The combination of returns, carefully processed, provides a knowledge of the construction layout of the facility and could, on the basis of change detection, detect the movement of personnel and equipment. Actual Doppler detection might sense finer details of the movements of equipment and personnel.

- **Spot Synthetic Aperture Radar**. The UAV's SAR is used to image the underground facilities adits, as cued by other sensors, either on-board (DIAL, etc.) or off-board (UGS and Tags), to provide immediate identification of the specific activity at the facility.

- **UGS Array**. In addition to the seismic sensors, a complementary UGS array, delivered and monitored from the air, tracks activity related to entering and departing the underground facility. Sensors allow vehicles to be classified, providing information on materials movements and possibly even arrival or departure of key personnel, especially in conjunction with ESM and tapping of landline communications. Other UGS can be used to detect trace quantities of effluents associated with the production of weapons, or the operation of command and control centers. These sensors can also be used to detect very small quantities of chemical or biological agents that leak from facilities or storage. UGS can also be used to trigger events (turn on beacons, change codes on tags, etc.) that can aid subsequent surveillance and tracking operations.

- **Tags**. Tags can be used to actively or passively provide tracking of vehicles and personnel on which those tags have been implanted, overtly or covertly. The tags can be implanted in equipment upon manufacturing, into raw materials at growth or mining, or onto vehicles and equipment later (decals, retroreflectors, fuel tank caps, gifts, placards, batteries, replacement tires, etc.) The location or activity could be determined by polling the tags from the UAV. Tags could also be placed in food or water supplies for the purpose of tracking the flow of such supplies, and hence determining the layout of the facility, or the location of personnel.

5.2.3.3 Enabling Technologies

The key enabling technologies for the Underground Facility Surveillance concept are:

- UGS seismic tomography devices and processing methods derived from extensions of technology used in minerals exploration, scientific seismology, medical diagnosis, and other three-dimensional materials imaging applications.
- Micro-miniature transponding tags with data storage and LPI transmission capability, and suitable for long range operation.
- Automatic analysis of DIAL (effluent spectroscopy) and multi- or hyperspectral EO signatures to determine activity, detect chemical/biological materials and agents, estimate numbers and types of personnel, evaluate status of personnel and equipment, and so forth.
- Chemical and biological detection sensors such as conductive polymers and enzyme-based electro-chemical technologies suitable for UGS and other applications.

5.2.4 Concept 4—All Condition Concealed Target Detection

5.2.4.1 Overview

Detection of fixed and mobile targets that employ CCD is a difficult task and one in which integrated multisensor operation has great power. Furthermore, it is essential that we be able to find, track, and identify these targets under all conditions of day/night and adverse weather. Figure 5-4 sketches a typical scenario in which a mobile missile battery is concealed under trees. Of the many possible sensor combinations, the one shown involves a space-based wide area surveillance sensor, a cued UAV foliage penetrating sensor, and an unattended ground sensor with air and geophones to detect noise patterns associated with targets. Since the target is mobile, the engagement timeline may be short. We thus employ a C^3I platform such as Joint STARS as both the fusion center and the engagement controller. Target location is passed to an attack aircraft which launches a munition with some combination of geo-coordinate guidance and terminal homing and with a warhead matched to the target, typically an area weapon such as a submunition dispenser.

5.2.4.2 Sensor Concept

In order to deal with concealed targets, this concept includes a combination of multiple sensor types, including space-based, airborne, and ground units, backed up by sophisticated signature analysis and data fusion processes. Key elements of the concept are:

Exploitation of Multiple Target Signatures. The following are some of the sensor phenomenologies that contribute to detecting and classifying concealed targets.

- **Wide Area Surveillance Radar**. By detecting and tracking the locations and movements of hostile units over time, we can focus CCD-penetrating sensors on specific regions of interest. UHR SAR and GMTI radars on satellite or UAV platforms provide this all-condition surveillance and tracking.

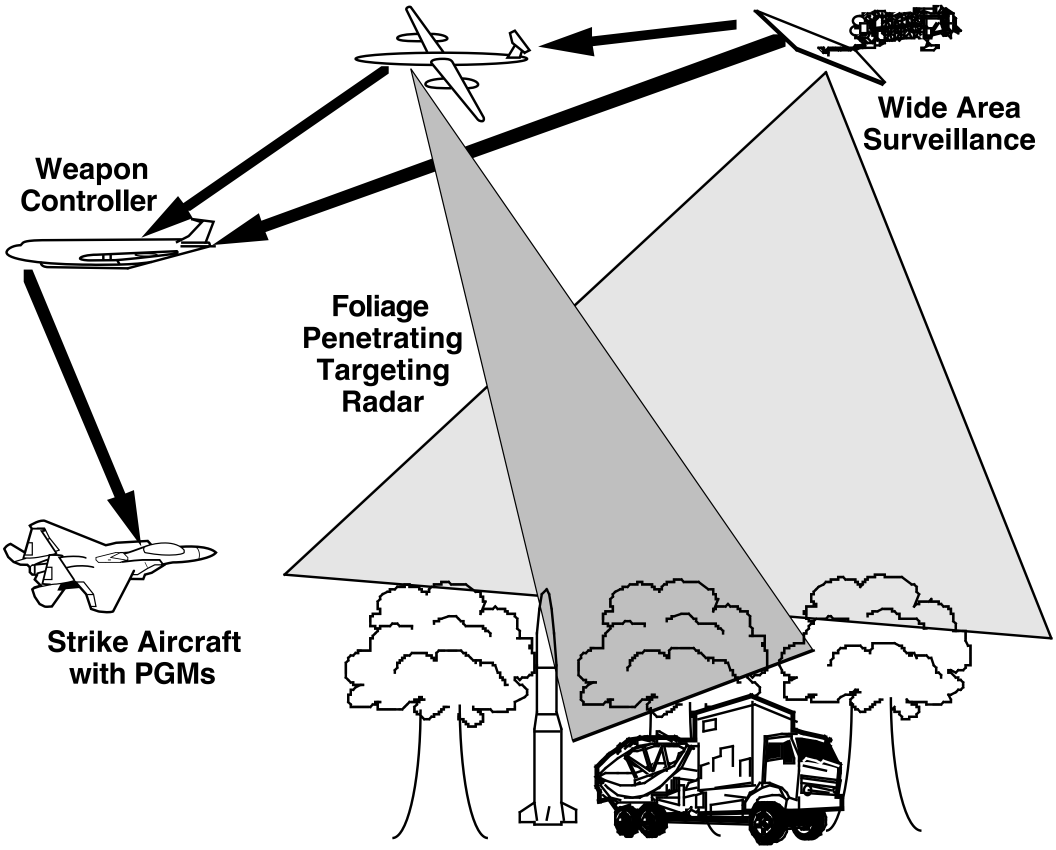

Figure 5-4. Typical Sensor Combination for Detecting Targets in Foliage

- **CCD-Penetrating Radar**. Foliage and many other CCD obstacles can be best penetrated at low radar frequencies. At the same time, target detection and classification requires high resolution, meaning broad bandwidth. A promising approach is thus a SAR sensor sweeping from, say, 20 to 600 MHz and mounted on a moving platform like a UAV to examine the area of interest from a wide range of angles to take advantage of primary reflection angles.
- **ESM/SIGINT**. Mobile targets will generally have to rely on RF communications that can be intercepted and exploited both for improved target location and classification and to provide warning of impending movements or attacks.
- **Imaging EO**. Although this concept stresses all weather capability, any information available from space or airborne EO imagers will be combined with other inputs both to track enemy movements over time and to improve the location and classification of targets. LADARs have some potential to detect subtle signatures such as foliage movements, and LIDARs may be able to detect engine exhaust or other emissions that betray the presence of concealed targets.

- **Ground Sensors**. In keeping with the complementary sensor concept of internetted, air-seeded UGS, we can use implanted acoustic sensors to monitor traffic at selected points and to listen for unique noise signatures associated with specific types of vehicles and equipment.

Near Real-Time Information Processing. Fast and effective signature extraction, target assessment, and fusion processing are essential to striking time sensitive targets such as mobile missile launchers or artillery. Our concept calls for distributed processing in which individual sensor platforms perform significant signal processing, feature extraction, and identification of targets or, at least, areas of interest, for example, by declaring the presence of man-made versus natural objects in a scene. Final data fusion is performed onboard an on-scene C^3I platform for speed and direct support to a weapon controller. The resulting solution is sent to a strike aircraft for prompt attack. Since CCD measures may defeat terminal seekers on munitions, the sensor solution may be required to provide precise target geo-coordinates to allow a coordinate guidance munition autopilot to put warheads within their lethal radius of the target.

5.2.4.3 Enabling Technologies

Each of the elements of the concept described above requires advanced technology to be effective. Some of these are available or will be in the near term, while others require significant development. Examples include:

- Affordable, lightweight, multimode space based radar sensors with significant onboard processing (see Section 5.2.7).
- HF wideband SAR radar and associated signature processing algorithms and hardware for penetration of foliage and other CCD.
- Affordable, covert UGS with embedded processing for recognition of specific acoustic signatures.
- Robust, LPI, jam-resistant data links with the necessary bandwidth for real time sensor data transmission.
- Data fusion algorithms and software capable of extracting high quality detection, location, and classification of concealed targets from a wide variety of real time data streams and historical information.

5.2.5 Concept 5—Weather Surveillance and Prediction

5.2.5.1 Overview

Even with all-weather high performance sensing and navigation, combat air operations will be significantly affected by weather. While the pictures of cloud tops familiar from current domestic weather satellites are useful, military aviators need accurate cloud and wind information at all altitudes. This concept addresses the need to provide highly accurate 6 to 12 hour forecasts, and greatly improved 24 hour and 5 day forecasts, anywhere in the world, especially over hostile territory where conventional weather observations are denied. It involves a variety of sensors on both satellite and UAV platforms which can deal with all combinations of cloud cover and winds. The concept also recognizes that ideal remote weather observing systems would almost certainly be unaffordable, so that innovative uses of improved technology are essential. A mixture of EO techniques, which are precise but have limited cloud penetration, and radar, operating from multiple UAVs and possibly supplemented by satellites, delivers the data to construct an accurate "nowcast" and to drive high fidelity models that produce the required forecast. Figure 5-5 indicates the primary elements of the concept.

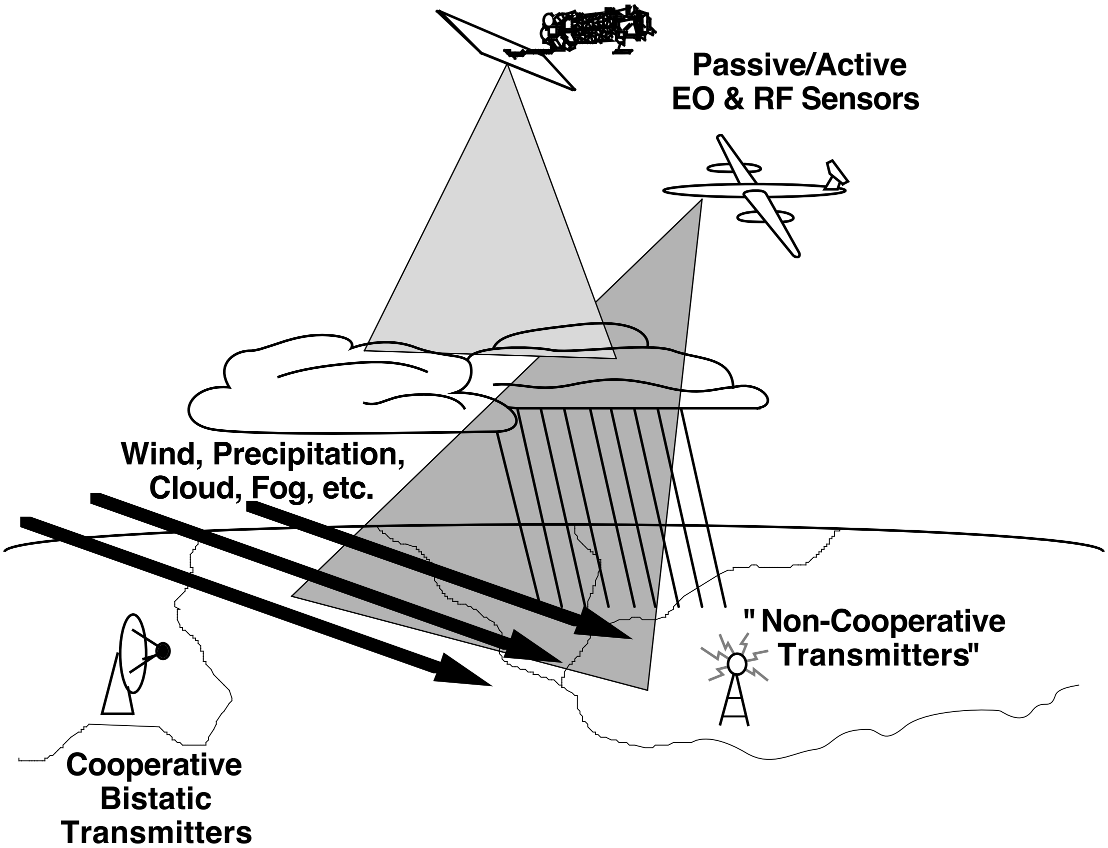

Figure 5-5. Multiple Sensors Contribute to Accurate Weather Awareness, Anytime and Anywhere

5.2.5.2 Sensor Concept

In order to make an accurate short-term prediction of weather over a given site, we need information on the synoptic evolution of weather patterns in the area over the previous 2 to 3 days as well as very precise knowledge of the current atmospheric state. Domestic weather forecasting relies on regular rawinsonde launches to collect data at various altitudes, supplemented by Doppler radar, meteorological satellite data, reports from aircraft in flight, and ground station readings, as input to predictive models. Atmospheric models and computing power have improved to the point where forecasting accuracy is limited mainly by the accuracy and spatial/temporal spacing of these readings. The primary variables of interest are temperature, dew point, pressure, wind speed, and wind direction at various altitudes.

Since we require remote sensing over denied territory, a very different approach is in order. Four general sensor types, which can be carried on satellites, high altitude aerial platforms, or both, are candidates for inclusion:

- **Passive IR**. Sensors with high resolution FPAs (benefiting from DoD investment in forward looking IRs [FLIRs] and other sensor systems) and sensitivity at multiple near, mid, and long IR wavelengths where there are atmospheric transmission windows and phenomena that yield useful information (e.g., water vapor absorption near 1.1 µm and CO_2 bands near 4.3 and 15 µm) provide information on water vapor, atmospheric temperature, surface ice, and other variables of interest when cloud conditions permit. IR resolution is inherently higher than microwave sensors can achieve but becomes progressively less useful as cloud cover increases, especially in layers.
- **Passive Microwave**. Radiometers operating from about 1 GHz through sub-millimeter wave bands can be used to image surface characteristics and clouds at frequencies below 90 GHz, temperature using the 60 GHz CO_2 line, and water vapor using the 183 GHz water line. Propagation through cloud is such that these sensors can map cloud tops and bottoms of multiple layers up to fairly high cloud densities. Synthetic Aperture Radiometry has been proposed as a way to improve horizontal resolution and to improve interpretation of data in the presence of liquid water in the atmosphere. Vertical profiling resolution is presently very limited and might require revolutionary techniques such as sensing occultation of GPS signals.
- **LIDAR**. Active EO sensors detect backscatter from atmospheric aerosols and can exploit a variety of phenomena, including fluorescence, depolarization, and DIAL to profile temperature, moisture, winds, pressure, water vapor, thin cloud tops and bottoms, aerosols and trace chemical species. They will operate at wavelengths longer than 1.5 µm. Like all optical techniques, they lose effectiveness as cloud density increases but have excellent resolution. LIDAR looks promising for detection of atmospheric turbulence through extension of techniques for measuring wind velocity.
- **Radar**. Radar systems on satellites or high altitude UAVs, typically operating in the range of 20 to 100 GHz, have the potential to provide cloud surveillance over broad areas and to penetrate essentially any multilayered cloud condition. Innovative approaches include tailored waveforms and more powerful data processing, especially high sampling rates, to improve discrimination of cloud returns from ground clutter and other interference. It may also be possible to use bistatic modes, including illumination from sources of opportunity such as radio and TV transmitters.

5.2.5.3 Enabling Technologies

Many technologies contribute to small, affordable, high precision, long lifetime weather surveillance sensors. Examples include:

- **Optical Sources**. The LIDAR portion of this concept relies on lasers and associated cryocoolers that are small, efficient, and highly reliable at the wavelengths of interest, especially mid- and longwave IR. Eyesafe solid state lasers are important for applications such as DIAL.
- **LIDAR and Passive EO Detection and Processing**. Sensitive, multiwavelength receivers, advanced signal processing for temperature profiling and other measurements, and sensitive Doppler modes for wind and turbulence resolution are all necessary to achieve the desired performance in affordable systems. These systems can benefit from materials, manufacturing, FPA design, and other technology improvements in the broader field of EO sensors. In addition, the inherently broad coverage of weather surveillance generates enormous volumes of data, making powerful onboard processing to extract features and reduce the volume of raw data to be transmitted extremely valuable.
- **RF Sources**. Efficient, high power sources at 94 GHz and above are needed for weather surveillance radars that can exploit all the phenomena of interest.
- **Phased Array Radar**. Extremely broadband radars, including large deployable antennas for satellites and designs suitable for high altitude UAVs, are needed to complement EO sensors to achieve the required capability. Development of Synthetic Aperture Radiometry has promise for improving the performance of passive RF imaging sensors.
- **Dual Use Technologies**. Despite the significant differences in their operations, military and civilian weather systems have much in common, and this synergism should be exploited to reduce development and acquisition costs.

5.2.6 Concept 6—Modular, Integrated, Multifunction Phased Array Based EO System

5.2.6.1 Overview

This concept deals with higher performance and more affordable ways to meet the continuing need for high performance EO systems on attack aircraft and other platforms. EO systems are important for functions that include situation awareness/threat warning, navigation and pilotage, A/A and A/G targeting and FC, and support for weapons such as laser-guided bombs. Additional potential applications include covert data links and improved IFFN. Future weapon systems need sensors with improved ability to penetrate weather and battlefield obscurants, more precise target location and identification, and improved compatibility with LO, all at reduced cost.

The major cost for most EO systems is in the gimbals and the precise pointing and stabilization. This is a body-fixed concept, with no gimbals and no mechanical stabilization. It is a modular design as sketched in Figure 5-6 that uses optical phased arrays for beam shaping and pointing analogous to a phased array radar. It also is a multifunction concept that has the potential to incorporate any or all of the functions listed in the figure.

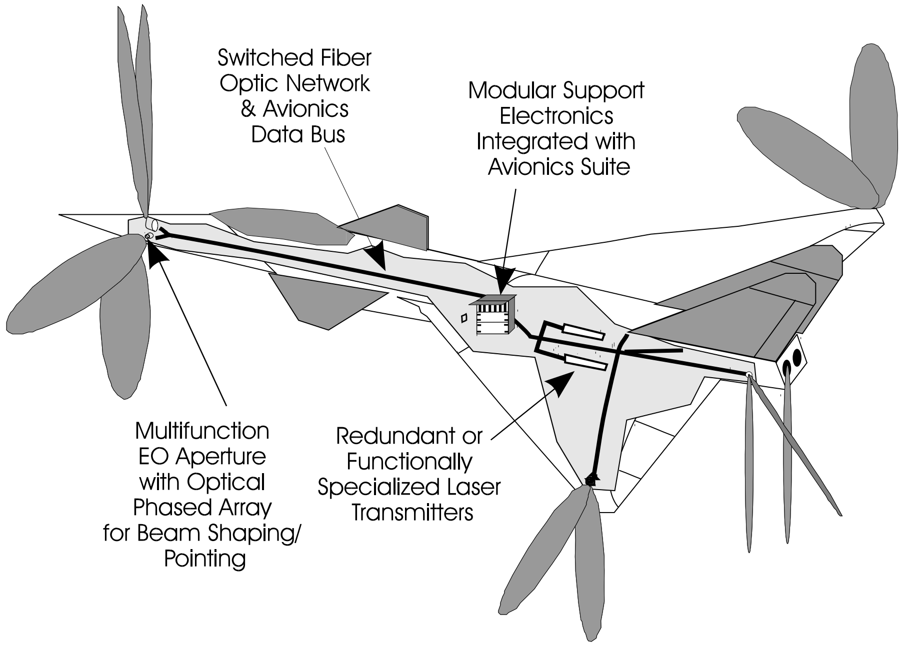

Figure 5-6. Integration of Multiple EO Functions in a Modular Sensor

5.2.6.2 Sensor Concept

The concept includes four to six apertures around the aircraft to provide 360° azimuth and top and bottom apertures, if required, for 4π steradian coverage. Each sensor module is a cylinder roughly 12 cm in diameter, with a 10 cm optical aperture, and roughly 20 cm deep. One or two system modules will be required as part of the plane's integrated avionics suite, connected to the aperture modules through fibers. There will be at least two laser transmitters, linked through a fiber switching network to each of the modular apertures. A single laser should be sufficient for designator and targeting functions, except for redundancy considerations. The network will allow any laser to transmit through any aperture. Laser transmitters should be capable of IRCM. A high rep rate, high duty cycle transmitter will be needed for covert high bandwidth communications. Primary laser receivers will be in individual aperture modules, although special purpose receivers could be centrally placed with signals sent over the fiber optic network.

The IR receiver will be a staring, microscanned sensor. Passive sensors can use a high field rate and an inertial system, so electronic stabilization and antialiasing will be used for low cost. One approach would be to combine a narrow FOV staring IR sensor with an optical phased array for wide angular coverage. This should allow target tracking to a fraction of a milliradian (called the detector angular subtends, DAS). Detailed processing would only occur in the region of a cue, provided by another sensor. Target acquisition accurate enough to put a laser designator on the target would then be used to deliver a laser-guided munition. The designator will be a low rep rate 1.06 μm solid state laser. The LADAR/target ID source will be a 1.5 μm laser system with direct detection. It will use high range resolution, two-dimensional angle/angle imaging, or three-dimensional imaging, for target ID. Missile warning will require wide FOV capability.

5.2.6.3 Enabling Technologies

A number of critical technology developments will influence the eventual shape of this system concept. Some of these are:

- **Optical Phased Array Technology**. We need to steer the laser beam rapidly over a 60 deg by 60 deg angular area for a 6 aperture concept, or 90 degrees x 60 degrees for a 4 aperture concept. Steering efficiency should be close to the cosine limit approached by microwave phased array radars. We also want to steer a narrow FOV passive sensor with the phased array.
- **Electronic Stabilization and Random/Natural Microscan**. Image stabilization is needed to eliminate aliasing artifacts in an image.
- **Fiber Optics**. We need the ability to transmit an image through a single fiber by inserting it and removing it at a focal point. This is easier for narrow-band laser images, since fiber dispersion will not be as much of a problem. This determines the location of array laser detectors, or passive broadband FPAs.
- **Clutter Rejection**. We also need the ability to remove A/A infrared search and track (IRST) clutter using large DAS, with rapid readout and electronic stabilization providing random sampling at higher angular resolution (e.g., 1 mrad DAS, 480 Hz readout, estimated sampling every 150 µrad or so based on random motion). If we can steer a narrow passive FOV, higher angular resolution will be available. Sensor data quality must support adaptive spatial/temporal processing to extract faint targets in severe clutter.
- **Pixel Ganging**. We need the ability to gang together pixels in an image for readout and processing purposes, and to focus on detailed readout of only selected portions of a focal plane array.
- **Multifunction Apertures**. We need the ability to conduct all functions through all apertures using the combined power of optical phased arrays, advanced FPAs, multifunction laser transmitters, switched fiber optic networks, and other elements of this concept.

5.2.7 Concept 7—Low Cost Space-Based Surveillance

5.2.7.1 Overview

This concept is based on a mix of high resolution radar sensors and imaging EO sensors on small satellites to provide a launch-on-demand capability to place a tailored constellation on orbit over an area of interest. When a crisis erupts, the first source of information is likely to be national assets and the historical database, followed a few hours later by information collected by manned aircraft available at sites local to the crisis. As soon as a day later, continuous coverage might be available from UAV's deployed from CONUS and based as close as possible to the theater of interest. If a crisis is anticipated to last for an extended period (more than 30 days or so), it might be economical to deploy a space based constellation of low altitude surveillance satellites that would be capable of providing near continuous coverage within the theater. If UAVs must operate at long ranges from friendly bases (say more than 200 nm), the cost of operations to achieve continuous coverage, overflight requirements, and reliable data downlinking all become more challenging. Pre-existing space-based sensors are unlikely to provide the level of coverage needed.

We envision a LEO constellation of 10 to 20 satellites in the proper orbital planes to achieve target coverage on the order of 10 minutes out of every 40 minutes. Using advanced but feasible sensor technology, reasonable production quantities, and a standard lightweight satellite vehicle bus launched on a single-stage-to-orbit booster, we can fly an individual satellite for as little as $25M with a lifetime of perhaps six months to a year. During time away from the target, each satellite downloads stored imagery, receives tasking, and orients and configures its sensor for the next pass. These assets operate as integral parts of the overall information gathering function, supporting surveillance, targeting, and warning functions with their data fused with other sources. Figure 5-7 summarizes the concept.

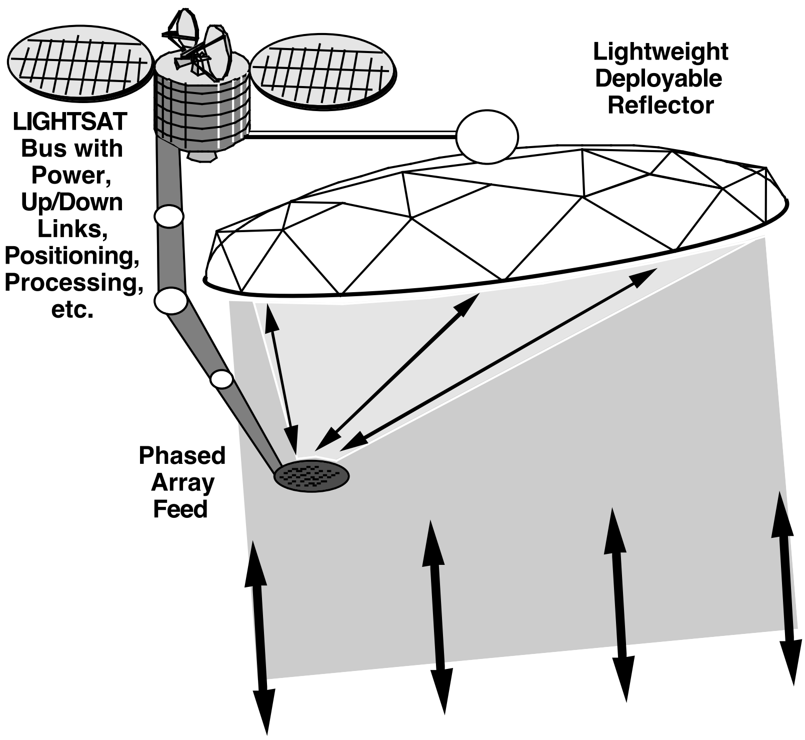

Figure 5-7. A Lightweight, Affordable Imaging Radar Satellite Can Provide Long Term, Tailored, Survivable Surveillance of an Area of Interest

5.2.7.2 Sensor Concept

To some extent, the crossover between continued use of UAV assets and launch of a satellite constellation will depend on the cost of the space assets relative to the operational costs associated with the airborne collection platforms. Thus the feasibility of space based surveillance depends on affordable satellites with suitable performance characteristics.

This concept uses a mixed constellation of SAR and optical imaging satellites, placed in 200 nm polar orbits by Pegasus or Taurus class boosters, and phased to provide short interval, near continuous coverage of a theater. A space-based surveillance radar satellite could provide better than 3 m resolution imaging and optical imaging satellites of the same weight could provide multispectral 1 m imagery in cloud free areas. At initial orbital altitudes of 200 nm, spacecraft lifetimes will be six months to about one year, depending on the level of solar activity. This light weight and short lifetime offer opportunities for innovative approaches to spacecraft design that may reduce the cost of the system. It may be possible to use commercial microelectronics with relaxed total dose radiation tolerance since the orbit is low and on-orbit lifetime is short. Additionally, it may be substantially less expensive to depend on fault detection and automatic error correction rather than demanding high levels of redundancy for fault tolerance.

Interferometric SAR, change detection, and MTI techniques, combined with ATR, ASC and data compression techniques, will dramatically increase the utility of the collected imagery. Spacecraft maneuvering (hence propellant mass) can be minimized by orienting the bus and antenna for an entire pass, then leaving attitude constant during the pass. This will trade some amount of ground coverage for lower complexity and cost, while successive satellite passes can be tasked to deliver the required coverage.

5.2.7.3 Enabling Technologies

- A dominant cost element for high duty cycle space-based SAR is the solar power system. Continued progress in cost reduction of GaAs solar cells and associated concentrators, power converters, and batteries will be essential. However, for a low cost system focused on a single theater, low duty cycle operation allows a smaller power system to charge batteries during the 45 minutes of sun exposure per orbit. Thus the solar array can be less than half the size and cost of conventional designs.

- Lightweight, deployable antenna technology compatible with the LIGHTSAT bus is essential. Designs for high gain GEO commercial COMSATs may apply here. High efficiency, wide bandwidth T/R modules or power tubes are another area that will be critical to affordability. Technology drawn from a number of aircraft and ground radar programs contributes to achieving the required cost/performance ratio.

- Onboard processing will convert digitized I and Q channel data into images prior to downlinking. The primary obstacle today is the power consumption, size, and weight of the processor and very large associated memory (1012 bits per pass). Advanced high density three-dimensional semiconductor memories will be available, but low voltage, low power operation will be essential.

- Either the downlink must support very high data rates (Gbits/sec) or there must be a large buffer memory to store imagery for lower rate download. In either case, technology advances are needed to make the satellite affordable. Within the time frame of *New World Vistas*, it may be preferable to use dense, high performance processors to endow even low cost satellites with high levels of autonomy; for example, onboard target identification might allow downlink of target data versus complete images.

5.3 Summary of Sensor Concepts

The picture which emerges from these concepts is of a feasible, affordable approach to greatly enhanced information gathering in the battlespace through a combination of advances in individual sensor technologies and, especially, cooperative sensor operations. In general, the concepts described deal with “difficult” targets, that is, those which are hard to detect, locate, track, and classify because they are inherently obscure, embedded in clutter and interference, or protected by CCD. Specifically:

- Sensors which endure over the area of interest and build time histories of enemy activity patterns are frequently invaluable in building situational awareness and allowing focused use of sensors to deal with difficult targets. In many cases, a combination of survivable UAVs and lightweight satellites can be employed, tailored to the nature, extent, and duration of a given operational scenario.
- The key to many sensor challenges lies in higher levels of dimensionality in the signature space, achieved by fusing the outputs of EO and RF sensors in multiple spectral bands plus, in many cases, ESM intercepts, ground sensors, and other specialized devices. This is both more effective and more affordable than attempts to build single sensors with the unaided ability to prosecute difficult targets.
- In a number of important scenarios, the ability to “saturate” enemy territory with large numbers of individually inexpensive sensors, especially UGS which are emplaced by aircraft and report data through aerial relays, offer a much better, and sometimes the only, approach to the required information gathering. This is truly revolutionary when compared to the historical view of surveillance sensors as few in number and high in performance and cost.

In every case we have examined, success in providing information from sensors to warfighters is greatly enhanced by an overall architecture that defines the functions, interfaces, and operating modes of the overall information gathering structure. Such a sensor architecture is properly seen as a major segment of the overall information architecture.